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Di-Muon Production with π^+ and π^-.

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ABSTRACT

Di-muon Production with π^+ and π^- Featuring a Very Large Acceptance Apparatus and High Sensitivity

It was pointed out before the discovery of the ψ in FNAL P332 that a measurement of the π^- to π^+ cross section ratio for di-muon production on a nucleus with equal numbers of neutrons and protons would be one of the most conclusive tests of the Drell-Yan mechanism and quark fractional charge assignments. This reaction is currently being studied in FNAL E444 in the muon lab. We propose to measure this ratio in the M2 beam of the meson lab as a function of $\tau\left(\frac{m^2}{s}\right)$, Feynman $X_{\mu\mu}$, $\cos\Theta^*$(di-muon decay angle with respect to the incident beam direction) and S(total center of mass energy). The experiment will be sensitive to a value of $\tau \leq .5$, $\cos\Theta^* \leq .85$ and to $X_{\mu\mu} \geq -.5$ for π^+ as well as π^-. The large acceptance of the apparatus makes it possible to detect events with $\cos\Theta^* = .85$ even for negative $X_{\mu\mu}$. The estimates of our sensitivity are based on the Feynman-Field quark distribution functions. We propose to measure both π^+ and π^- cross sections at 150 GeV/c for a ratio comparison and the π^- cross section at 280 GeV to investigate scaling. A total data taking time of 750 hours is required.

I. Introduction

The notion of particles being composed of quark constituents has evolved and solidified considerably since P332 was first proposed. Indeed, it is now fashionable to interpret high energy weak interactions, electron and muon deep inelastic scattering, large P_t scattering as well as direct di-muon producton in terms of the quark model. In addition, QCD has provided a possible theoretical basis for this constituent picture. However, attempts to find such fractionally charged particles in the debris of nuclear collisions or in very dilute concentrations in bulk matter have so far been unsuccessful. Hand waving arguments to the effect that somehow the quarks "dress" themselves and appear only as integral charged combinations still leave much to be desired.

In the meantime techniques for the study of di-muon production have evolved and some real advances made. The experimental methods developed in E439 make it possible to propose a much improved version of P332.

II. Physics goals

A very high sensitivity experiment measuring the reaction $\pi^{\pm}$ + Nucleus $\to \mu^+\mu^-$ + anything will clearly be extremely important in elucidating the constituent model and quark properties. Figure 1 shows the vertex we are probing and illustrates the strong interaction symmetry in π^+ and π^- interactions.

The structure functions of the pion are really quite spectulative at present, unlike those of the nucleon which have been measured in deep inelastic lepton scattering. We have used both the structure functions of

M. Dong Van(MDV) and Feynman-Field (FF) in investigating what sensitivity is necessary to probe the structure, so that sea quark effects are negligible and an interpretation in terms of valence quarks can be made. Figure 2 indicates the expected cross section ratios when sea quark interactions are included for π^+ and π^-. This is done for $\tau(m^2/s)$ of .05, and .2 and .4 and is equivalent to di-muon masses of 3.75, 7.51, and 10.6 GeV at 150 GeV incident pion momentum. We have determined that 150 GeV is about an optimum momentum for comparison of π^+ and π^- cross sections. At 150 GeV a good π^+ to proton ratio is possible and it is easier to reach large values of τ.

Note that the ratio closest to 4. is obtained near $x_{\mu\mu} = 0$. That is why we have designed a large acceptance at $x_{\mu\mu} = 0$. ($x_{\mu\mu}$ is the ratio of the di-muon longitudinal momentum to the maximum possible di-muon momentum.) The variation in ratios is due to the sea quark contamination which is worse at low τ and $x_{\mu\mu}$ near 1.

At the point where the best measurement of the quark charge is made it is important to measure the angular distribution of the muons well. It is expected to be $1+\cos^2\Theta^*$ if quark annihilation is dominant and clearly it is important to the interpretation to check this. The proposed design would have an aperture capable of detecting decays with $\cos\Theta^*$ up to about .85. Other processes such as resonance production and decay might be expected to be isotropic in $\cos\Theta^*$ and thus be detected if present by measuring the angular distribution as well.

By measuring the cross section with 280 GeV π^- we will be able to check the scaling domain and thus the point-like nature of the constituents. We expect to have a sensitivity to measure values of τ up to .5 or a mass of over 16 GeV. This would also give a good look at Υ production with π^- at this energy over a large region in x_T and decay angles.

III. Experimental Technique

Figure 3 shows a schematic of the solid iron magnet configuration designed for the 150 GeV incident pion energy. At 280 GeV an additional magnet will most likely be added to cut down on hadron shower punch through. This will keep the acceptance approximately the same. The magnets have been designed so that they go together with sections that are easily moveable by the meson crane (see Figure 4). They will utilize water-cooled coils and the small iron magnet can possibly be designed to go to more than 30 kG.

Figures 5 and 6 show the deployment of PWC's and hodoscopes for the detection and triggering on the muons after they emerge from the iron magnets. The limit of six MWPC planes per muon track has been tested and shown to be sufficient in a E439 test run in April, 1977. The hodoscopes will consist of two planes of horizontal and two planes of vertical elements to allow selection of good di-muon events. Trigger boxes similar to those built for E439 may be employed to reduce background triggers. This experiment is expected to need only a subset of the equipment needed for the proton weak interaction asymmetry experiment and thus can utilize this equipment in the configuration shown in Figures 3 through 6.

It appears feasible to include in the plans for the post mesopause M2 beam, provisions for a modest intensity pion beam (x 10^7 π^- at 150 to 280 GeV). We would work with the meson planners toward this goal. The π^+ rate is based on 1.8×10^{15} protons per hour on Meson target, a 3 interaction length Be absorber, and 500 seconds of beam per hour with 80% duty factor. Fifty percent of the π^+'s can be tagged unambiguously at a 2.5 10^9 π^+ per hour rate. 3.5×10^9 π^- per hour can also be tagged unambiguously.

IV. Rates

In one-half the events the two muons bend towards each other in the vertical plane. For these events the detection efficiency is nearly 100%. The asimuthal acceptance is approximately one-half and the polar acceptance ($\cos\theta^* \lesssim .85$) covers about 80% of the decays. This leads to our overall detection efficiency of approximately 20%. Based on this and a model dependent (MDV) production estimate, we expect one event from π^+ and four events from π^- at a mass of 11.5±.5 GeV(per 250 hours of running). For the 280 GeV running we expect one event at m = 16±1 GeV.

Below the T region at m = 7.5±1.0 GeV we expect about 100 events for π^+ and 400 for π^- in 250 hours. This would give a statistical error on the charge ratio of about 10% at a τ of .2.

V. Summary

In a 750-hour data run we expect to contribute the following information to the constituent picture. In addition to the pion structure functions at large X (up to .7) we will:

(1) test the point-like structure over a large range in $x_{\mu\mu}$ $(-.5 < x_{\mu\mu} < 1)$;

(2) test spin ½ quark annihilation with $\cos\Theta^*$ measured up to .85 even for negative $x_{\mu\mu}$.

(3) Test the fractional charge assignments for the up and down quarks.

We would expect to be ready for this experiment immediately after the Meson 1978 shutdown.

FIGURE CAPTIONS

Fig. 1 Diagrammatical representation of gluon process that might modify the Drell-Yan rates. This diagram is meant to emphasize the cancellation of these processes in the cross section ratio.

The external quark line produced gluons are not expected to contribute to the direct lepton production process at large di-lepton mass or near 90° in the center of mass where the Drell-Yan process peaks. These are the wee partons and carry a very small fraction of the particle momentum. Any modifications to the photon propagator are also identical and will cancel.

Fig. 2 The cross section ratios for τ = .05, .20 and .40 using the M. Dong Van structure functions.

Fig. 3 This is a schematic of the active areas of the magnets in the vertical and plan views.

Fig. 4 Some details of the magnet construction style are shown in this schematic.

Fig. 5 This depicts the PWC and hodoscope deployment used to cover the very large solid angle acceptance.

Fig. 6 Some relevant details of the PWC arrangement are shown in this schematic.

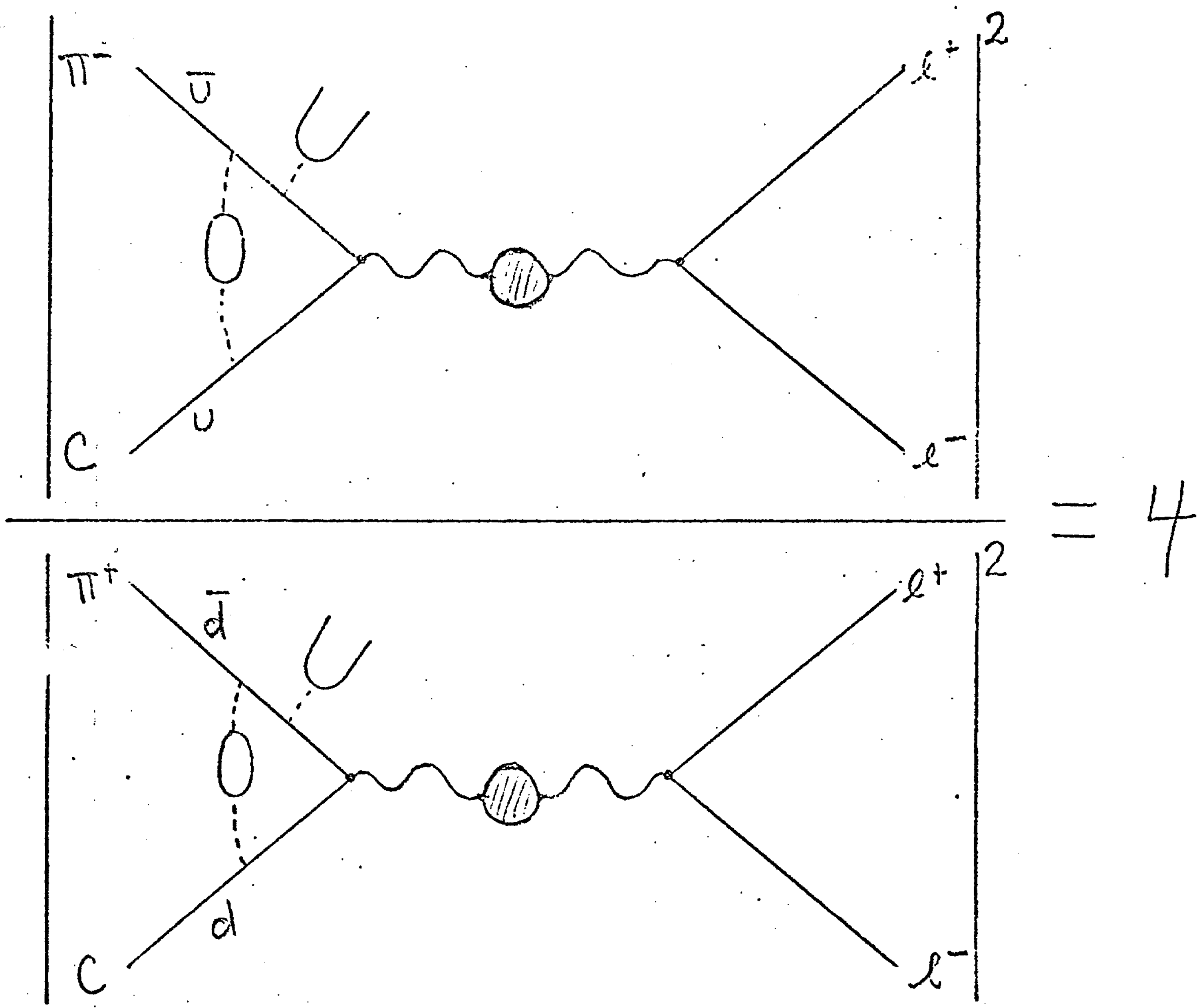


Fig. 1

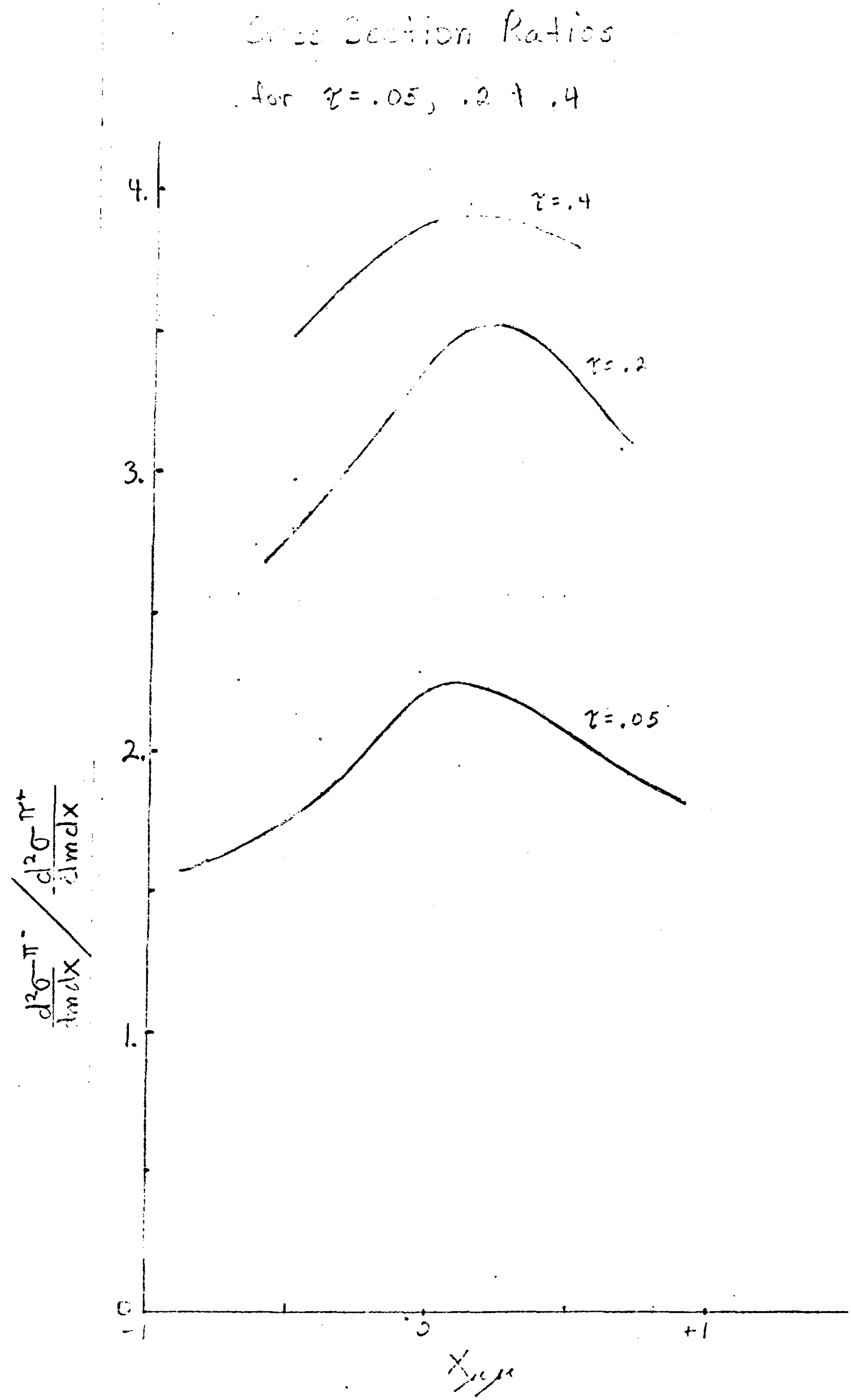

Cross Section Ratios
for $\tau = .05$, .2 & .4
4.
3.
2.
1.
0
$\tau = .4$
$\tau = .2$
$\tau = .05$
$\frac{d^2\sigma^{\pi^-}}{dm\,dx} \Big/ \frac{d^2\sigma^{\pi^+}}{dm\,dx}$
-1
0
+1
$x_{\mu\mu}$

FIGURE 2

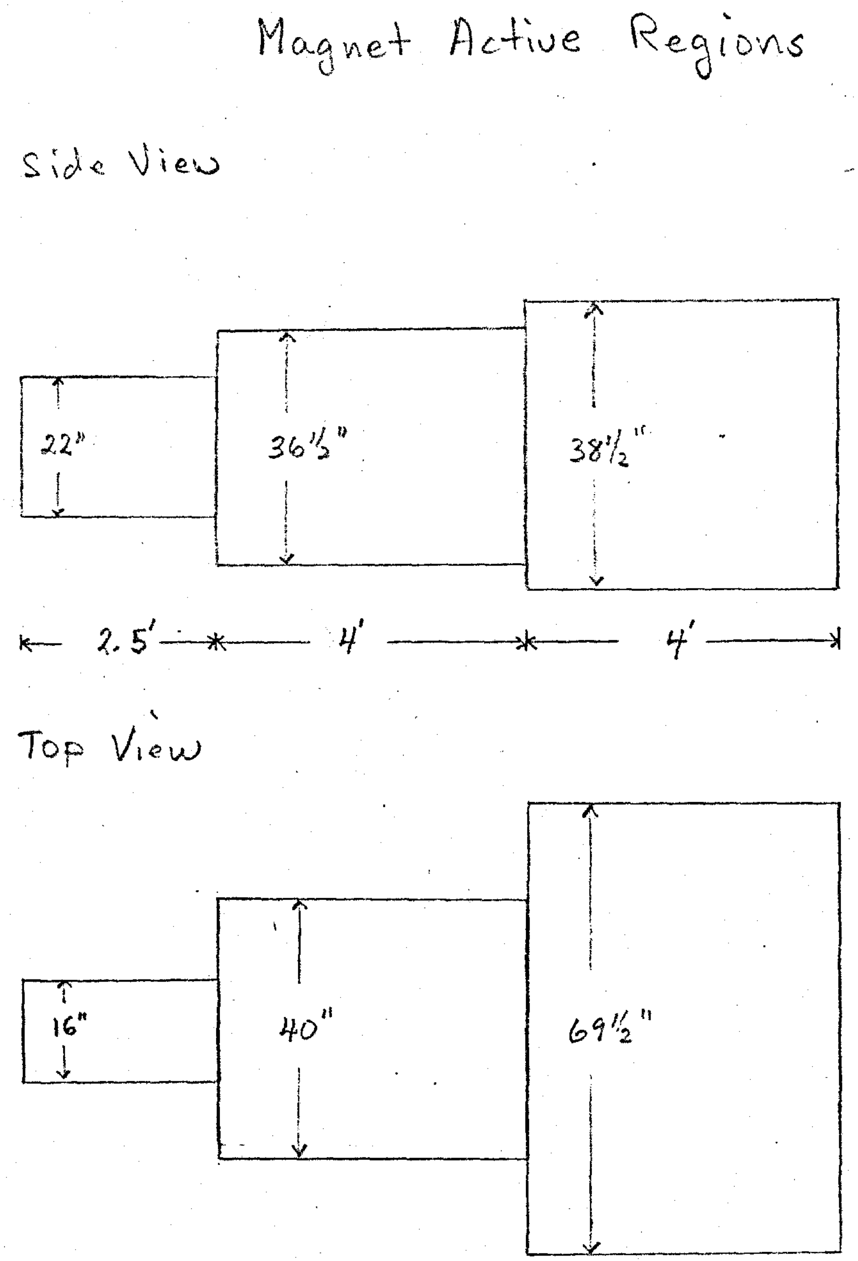

Magnet Active Regions
Side View
22"
36½"
38½"
2.5'
4'
4'
Top View
16"
40"
69½"

FIGURE 3

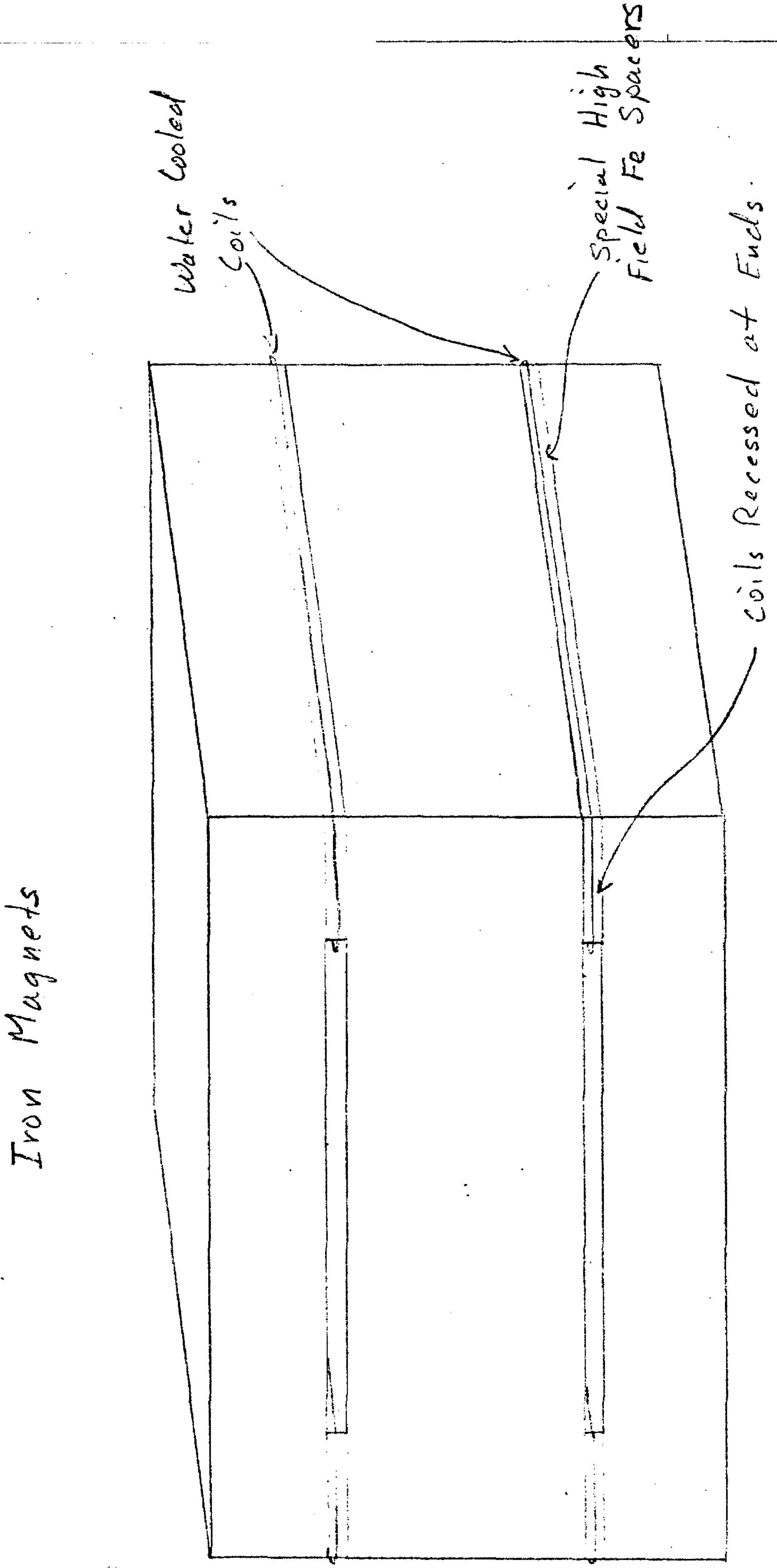

Iron Magnets
Water Cooled Coils
Special High Field Fe Spacers
Coils Recessed at Ends.

FIGURE 4

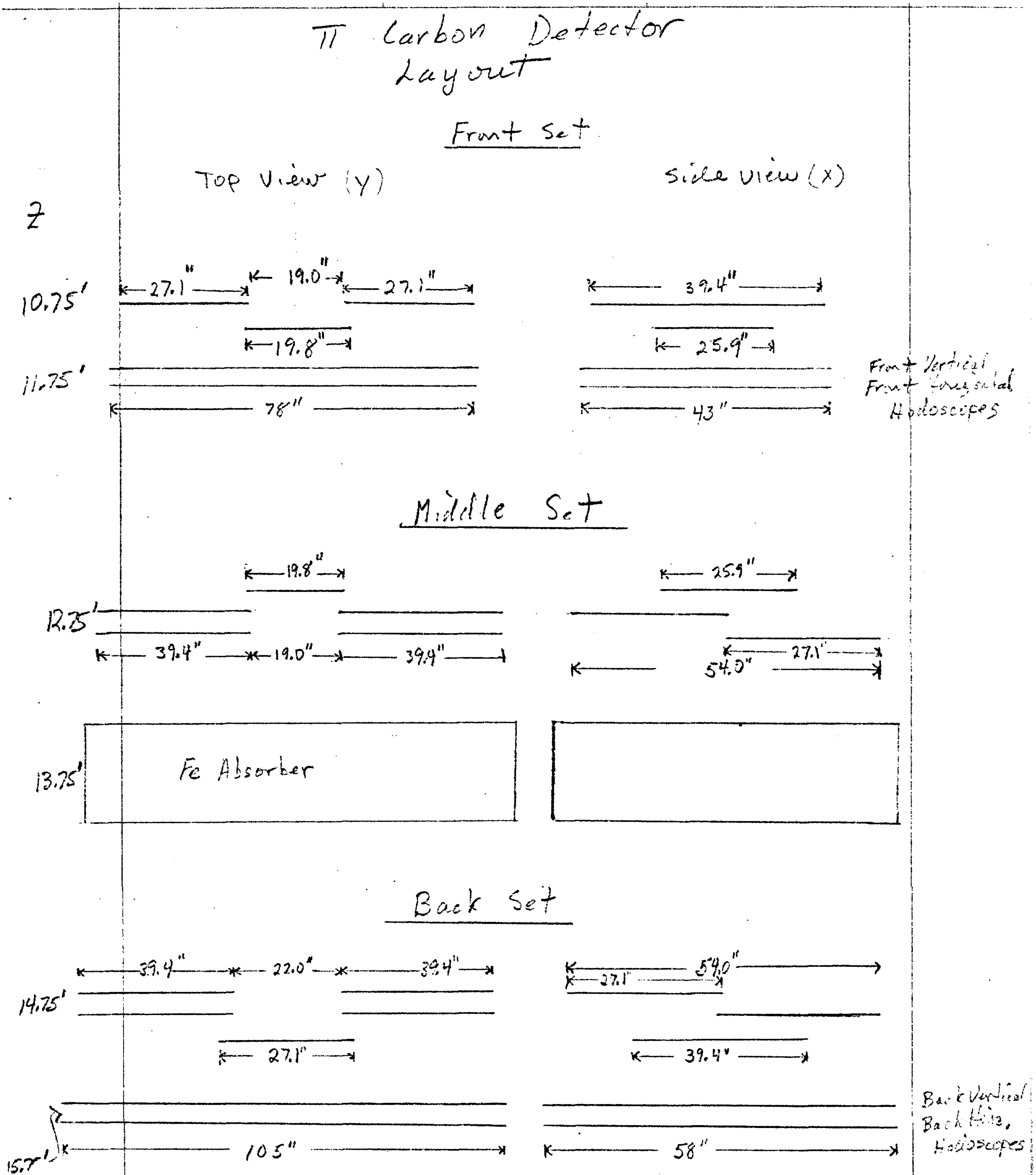
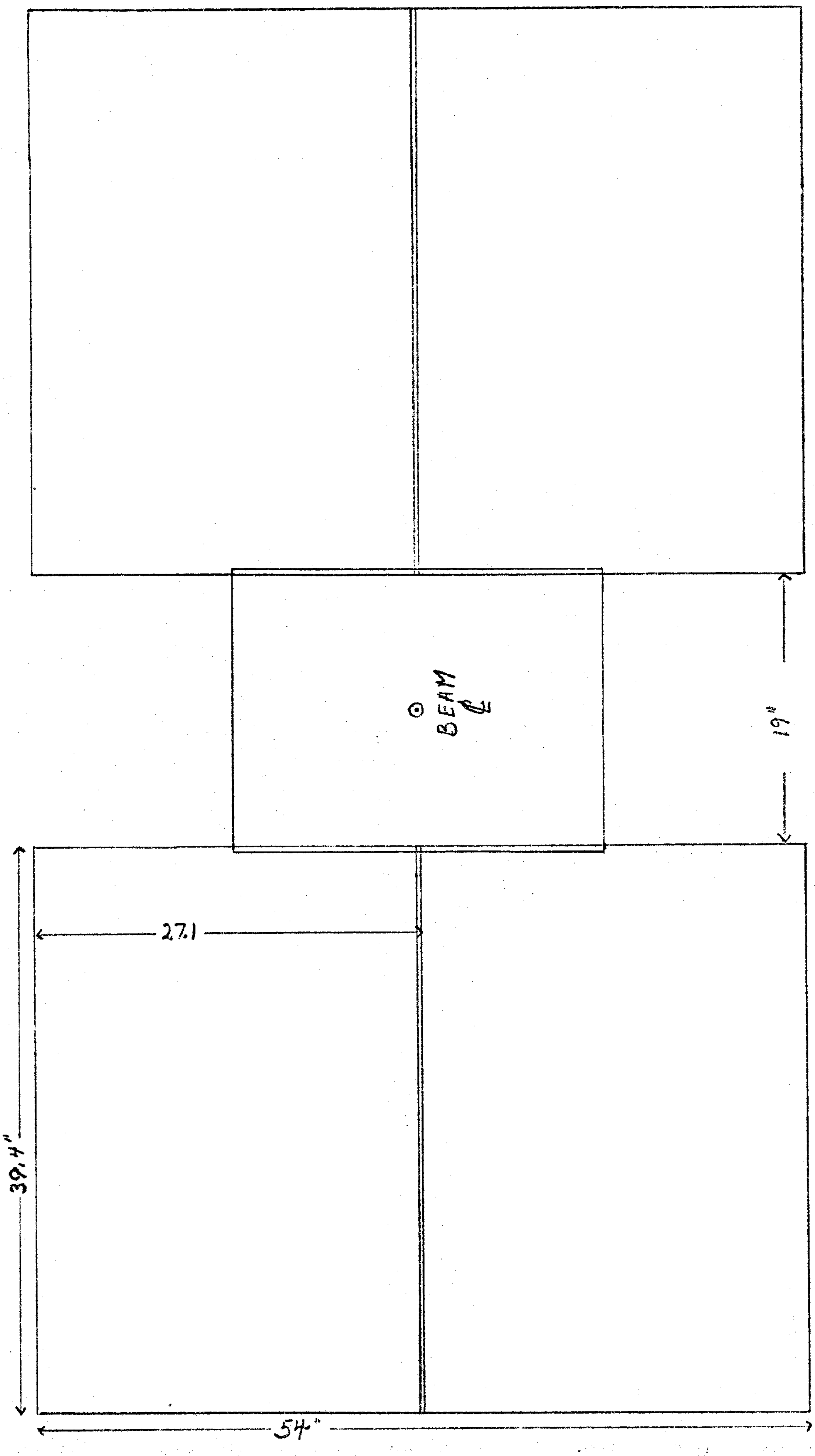

π Carbon Detector Layout
Front Set
Top View (y)
Side View (x)
z
10.75'
27.1"
19.0"
27.1"
39.4"
19.8"
25.9"
11.75'
78"
43"
Front Vertical
Front Horizontal
Hodoscopes
Middle Set
19.8"
25.9"
12.75'
39.4"
19.0"
39.4"
27.1"
54.0"
13.75'
Fe Absorber
Back Set
39.4"
22.0"
39.4"
54.0"
27.1"
14.75'
27.1"
39.4"
Back Vertical
Back Hor.
Hodoscopes
15.7'
105"
58"

FIGURE 5



PWC Layout (Middle Set)
Active Region Shown

FIGURE 6